

Fast silicon to silicon wafer bonding with an intermediate glass film

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Silicon to silicon wafer bonding utilizing an intermediate sputtered glass film was presented by Hanneborg et al [1] as a promising sealing technique for highly structured wafers at temperatures < 450°C. We have optimized this technology and present a fast bonding process with high yield numbers (93-100%) and strengths (9.2-10.0 MPa). The effects of sputtering in different gases and bonding in vacuum or at atmospheric pressure are verified. We present pull test results with focus on geometry dependence.

Silicon wafers were structured in KOH with a mask for pull testing. Blank or patterned wafers were covered with 0.3 µm of silicon oxide and 3 µm of sputtered Pyrex #7740. A sputter gas of pure Ar or 20% O₂ and 80% Ar was selected. The sputter rate for pure Ar was twice as high as for the gas mix with 20% O₂. Bonding was performed with a SUSS SB6 bonder in either vacuum or at atmospheric pressure. The voltage was ramped linearly up to 100 V for two hours or ten minutes and subsequently turned off. Before applying any voltage, the wafers were held at the bonding temperature (350°C) for ten minutes to achieve a uniform temperature and some stress relief in the glass. Two silicon wafers, one patterned in KOH, were fusion bonded for comparison. Annealing of this wafer couple was performed at 1100°C for two hours.

The fast bonding processes resulted in slightly stronger bonds than the slow bonding processes. Values from pull tests of mesa structures (4 mm²) are presented in Table 1. Typically, about the same amount of charge was moved during the fast and the slow processes. By ramping the voltage slowly, the probability of electrical breakdown during bonding is decreased, but a short throughput time is crucial for a commercial process. With two hours or ten minutes ramp time, a substantial bonding current was always measured, and electrical breakdown did usually not occur. Conversely, electrical breakdown took place before any bonding current could be observed when a “zero” ramp time was tested. The bonding yield for each of the fast bonded wafers ranged from 93 to 100%. In work presented by e.g. Drost et al [2] and Weichel et al [3], process times of 1-2 hours were used to achieve high yield numbers.

Other research groups have reported that the sputter gas has an effect on the residual stress, the refractive index and the bonding quality of the glass [2,4,5]. From the fracture surfaces, it was observed that fracture typically occurred inside the glass for the wafers with a film sputtered in an oxygen rich gas and at the bonded interface for the wafers with a film sputtered in pure Ar. For equal bonding conditions, the average bonding strength was largest for the wafers sputtered in pure argon. The observations indicated that the bulk of the film sputtered in pure Ar was stronger than both the bonded interface of these wafers and the bulk of the film sputtered in an oxygen rich gas (after this specific bonding process - slow/atm). The bonding process with the film sputtered in pure Ar can thus probably be further optimized (e.g. with

an increased maximum voltage) until fracture occurs within the glass. If a too high voltage is used, fracture is expected to initiate at the glass/oxide or oxide/silicon interface due to segregation of sodium [6]. Wafers with a layer of PECVD nitride, as a sodium barrier between the glass and the oxide, have been bonded to wafers patterned in KOH. The bond strength will be measured.

Table 1: Pull test results from mesa structures (4 mm²)

Sputter gas (#wafer stacks)	Bond process	Charge moved (mC/cm ²)	Bond strength (MPa)
100% Ar (2)	Slow/atm	7.5 / 7.6	8.9 ± 3.2
With O ₂ (1)	Slow/atm	5.7	6.1 ± 1.8
With O ₂ (1)	Slow/vac	-	8.2 ± 3.5
With O ₂ (2)	Fast/vac	9.6* / 13.3*	9.2 ± 4.1
With O ₂ (3)	Fast/atm	5.1 / 4.9 / 9.2	10.0 ± 4.0
No glass (1)	Fusion	NA	18.8 ± 8

*Charge moved before electrical breakdown included.

As earlier reported [6], the average strength of wafers bonded in vacuum was slightly lower than for wafers bonded at atmospheric pressure. An equal observation was made during regular anodic bonding of Pyrex #7740 glass wafers to bare silicon wafers and silicon wafers coated with aluminum. The observations can be explained by a better thermal distribution at atmospheric pressure than in vacuum, but the role of water in the bonding process should also be considered [7].

Influence of pull test structure geometry was tested for frames of different widths, 200, 400 and 800 µm. The related bond strengths were 27, 16 and 15 MPa for the fusion bonded wafer, and 13, 11 and 9 MPa for one of the wafers bonded with an intermediate glass film. The difference in geometry dependence (less dominant where a glass film was present than for the fusion bonded wafers) could be explained by the dissimilar mechanisms for fracture initialization and propagation in the two systems. For the fusion bonded wafers, a wide variety of fracture surfaces was observed, predominantly in bulk silicon. For the wafers bonded with an intermediate glass film, more regularly shaped fracture surfaces of glass were observed. Fracture into the bulk of the silicon was rarely observed for these wafers. Numerical analyses will be performed in order to try to predict the observed geometry dependence.

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